INTRODUCTION OF SIX SIGMA TOOLS INTO THE SUPPLY CHAIN QUALITY MANAGEMENT OF FEED PRODUCTION

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ABSTRACT

Primer agricultural products and by-products of the food industry provide the mass of animal feeds. These ingredients have great variance in their quality that influences the feed product. Six Sigma tools helped to understand and provide solutions to manage the variance occurring in the supply chain. Due to the sourcing and the nature of these raw ingredients, the probability, that the feed product meets the target values, may need to be considered and if needed, increased at the manufacturer.

1. INTRODUCTION

The most of the literature in relation to Six Sigma refers to industrial manufacturing processes that intend shifting the standard of their performance from +-3σ (93.32% long term yield) to +- 6σ (99.99% long term yield). Little research had been done in the applicability of Six Sigma in agricultural production systems in particular, where natural and environmental effects influence yield, standard performance, quality and efficiency significantly. Generally speaking, Six Sigma improves the way that any process works, hence the deployment of Six Sigma tools into industrial compound feed manufacturing, formulation and the quality management of its supply chain. The toolbox of the methodology provides help in data collection, conducting analytical assessments, solving performance problems and optimizing processes. The focuses on quality improvement, cost reduction and improved delivery performance, resulting in higher profits and customer satisfactions. It is important to underline, that in case of compound feeds, the customer needs also include the physiological needs and health of the livestock consuming the final product. The reduction of unwanted variation in outputs with critical importance to customers by finding and eliminating causes of defects in processes is the target of the Six Sigma approach. The understanding of critical-to-customer characteristics and the variability around their averages is necessary to focus on the variables that control these functionalities. (Stamatis). Six Sigma approach also ensures continuous improvements. Even though reaching Six Sigma performance is absolutely challenging and not the ambition of a compound feed producer, the toolbox of the method still can help to improve quality. Six Sigma projects focus not only on problems but also on the opportunities.

3. LITERATURE REVIEW

In the EU-27, meat and animal products had the value of 136 billion € in 2009. This is 42% of the total farm production. Farm animals consumed 465 million t feedstuffs, and this takes the biggest chunk of animal production costs (i.e. up to 77% of the farm gate value of poultry). 30 % of the feeds are considered to be industrial compound feeds that represent 20% of the estimated 740 million t global compound feed production. 48% of the total feed materials are cereals. (FEFAC, 2010)

To maximize the production performance of the animals their nutritional needs must be fulfilled on the optimal level through feeding stuffs. At the same time, the cost of feeds needs to be kept at the minimum in order to increase the efficiency and profitability of the animal production. Modern compound feed formulation uses powerful software tools to calculate the least cost diets that fall into the optimal ranges of various nutritional parameters. The calculation method of these software tools is based, in most of the cases, on linear programming, where the linear objective function is the cost. The ingredients available for the formulation are populated with their typical, expected nutritional values and prices in the tool that calculates the optimal combination of the raw materials meeting the nutritional or other requirements of the product. Ingredient nutrients are varying and hardly ever known accurately in reality. Each uncertain ingredient nutrients, as variable inputs within the formulation model, are assigned a "best guess" estimate. Assuming symmetrical probability distributions of ingredient nutrients, the expected nutrient levels of the product will be achieved only 50% of the times.

As a solution to achieve more reliable nutritional composition of the product, Nott and Combs (1967) proposed the use of a safety margin for each nutrient by subtracting one-half of a standard deviation from the mean value of the nutrients. In this way the probability of meeting an animal's requirement would be higher. Pesti and Miller (1998.) states that higher than 50 % probability of success can be achieved by adding safety margins to the rations, which, in terms of concept, is closely related to stochastic programming.

Roush et al. (2004.) identified the variability of feed ingredient nutrients as a major risk of diets having insufficient nutrients. As a nonlinear input variable this variation breaks the linearity of the program and it has been proven that the linear program with a safety margin would over formulate at a higher than requested level of probability Roush et. Al. (2007.) The method of stochastic programming would provide better accuracy in meeting the requested probability levels and reach better controlling of nutrient variation.

Broers (2009) pointed out that the formulations should take the real ingredient quality of every lot into account during production □ptimized□□n to reduce the nutritional variations of the final product. However, often, the analysis of parameters of conventional raw ingredients is difficult or takes longer time. Feed producers are not always equipped with on-site laboratory to control all quality characteristics. Raw material nutritional analysis and data processing to derive means and standard deviations are done retrospectively. (Roush, 2004.) By the time the data is available about a batch, it is likely to be mixed and fed to the animals. The least cost and the most accurate diet could be formulated if the raw materials had limited or no variations at all, which is never the case, particularly for primer agricultural products.

Variability of quality attributes of a feed ingredient may occur due to multiple vendors, seasonality, processing variations of the supplier, deviations of laboratory analysis methodologies. In order to minimize the variability and accurately formulate diets the nutritionists must assess which ingredients impact the product performance significantly and statistically analyze and evaluate the distribution of the characteristics of the ingredients.

Raw material batches, even being from the same type, may significantly differ from each other due to different sources or supplier processes. Supplier quality management activities could address those raw material characteristics that cause significant deviations in the end product, and the cost benefits of this approach can be quantified by running simulations for diets based on the improved ingredient nutritional profiles. The measurement and analysis of quality data is necessary not only for accurate ration formulation, but the conclusions drawn from the analysis also must drive essential supplier quality development processes.

Shewhart (1980) defined quality that can be described as numerical measurement, which makes possible to see if the quality of the product for a given period differs from that for some other period taken, as a basis of comparison. It can be also the comparison of product qualities for two or more periods to determine if the differences are greater than should be left to chance. The establishment of standards is essential for industrial quality control and the quality requirements should be expressed as quantitatively measurable physical properties.

Deming (2000) underlined the importance of standards and measurement in buyer and seller relationships. The specification of an item is meaningless without operational definition. It must contain quantitative attributes and refer to the measurement considering that the instruments are in statistical control. The principles, laid down by Shewhart and Deming, provide the universal foundation of modern quality management.

Modern feed formulation requires a disciplined, systematic, data based approach. Nutritionists must define the customer requirements, measure, analyze, improve and control the variations occurring in ingredients, feed products that impact the performance of the target animal group. These are the typical steps of Six Sigma methodology for minimizing mistakes and □ptimized□ value. Schroeder et al. (2008) indicated that one of the distinctive features of Six Sigma from TQM was the higher emphasis on data and the use of specific metrics to highlight the importance of process improvements and encourage difficult but attainable goals for improvement.

The validation of the problem statement happens in the define stage by reviewing existing data to confirm that the problem exists, it is important to customers (Voice of the Customer), it is important to the business (Voice of the Business) and it can be improved. This step includes the creation and validation of process maps, the development of project plans with key milestones. The measure stage reviews the current state of the process (baseline capability analysis, SIPOC Supplier – Input – process - Output – Customer diagram, control charts) and reliable data on critical inputs and outputs are collected in terms of quality, speed, costs. Of course a capable measurement system must enable these tasks. The Analyse stage verifies those causes that affect the key input and output variables (root cause analysis, narrowing potential causing through Pareto analysis, statistical analysis to confirm cause-and-effect relationship, or strength of the relationship) (Voice of the process). In the Improvement phase potential solutions are developed, evaluated, and the □ptimized. Lastly, in the control step project completion takes place with launch implementation, auditing and validate the results, and performance. (George et al. 2005)

In the supply chains, specification limits of the components (ingredients) are usually set by the buying company. For the end-product manufacturer, often the product specifications are set by the customer. Quality is determined as two sets of characteristics: the characteristics of component parts (lower-level), and the characteristics of the product (higher-level). The proper definition of the specification of the lower level characteristics is important, because these affect the higher-level quality characteristics. In Six Sigma context parameter and tolerance design are included in the determination of these lower level specifications (Park, 2008).

According to the Six-Sigma based on Taguchi's loss function, additional cost incurs when the supplier performance moves away from the target in the specification. Therefore, supplier developments should target getting a characteristic to be on target value with as little variation as possible that goes beyond managing suppliers to stay within the specified range defined as lower and upper limits. If the distribution narrower than the specification limits, it is possible to make all or nearly all of the units to match the specification, especially is the distribution is centered around the target. (Ross, 1996)

3. METHODS AND MATERIALS

In the case study, a basic pet food product was taken as an example. The diet had been formulated from 9 ingredients (wheat, maize, wheat bran, digest, choline supplement, calcium carbonate, vitamin and mineral mix, pork fat, and poultry meal) and on 18 nutritional parameters in WinFeed 2.8 software tool with linear programming. The nutritional profile of the ingredients had been populated with their measured averages on each parameter in the linear programming tool. Even though the raw ingredient nutrients had average figures in the software, the set of end product analysis indicated varying results on calcium against the maximum level in the product specification (1.4%), and this characteristic becomes the target of the theoretical improvement project. With the help of Six Sigma tools a process map had been drawn, the possible inputs have been listed in cause-effect matrix, Pareto diagram were made to assess which ingredients may influence product calcium levels the most. Statistical analysis of data and diagrams were made with SPC for Excel software. After these steps, the variation of calcium content of the ingredients was analyzed in histograms and also capability analysis was carried out on the data per suppliers. The cost impact of using the material from one or the other vendor had been assessed with the formulation tool, where the different average Calcium levels were populated and the diet was re-optimized.

4. RESULTS

The formulation process map provides a visual explanation of the operation. To formulate the diets accurately, ingredient nutrients, prices are needed from the supply chain and the product specification is driven by the animal needs and other customer requirements. The problem with the occasionally occurring high calcium levels is belonging to the finished product, therefore every element that is before the end product stage may potentially have impact. Also, once non-conformities are recognized, corrective and preventive actions can be taken in the steps beforehand the place of occurrence.

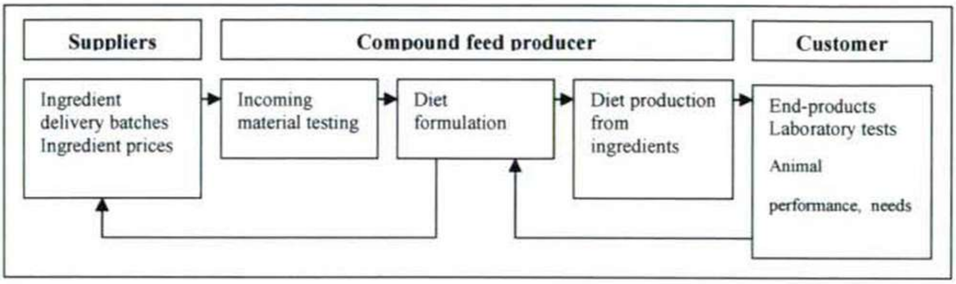

Figure 1: Process map of animal feed formulation

The most important and possible causes of high calcium levels in end-products have been captured in cause-and- effect analysis as inaccurate scales weighting incorrect ingredient amounts, homogeneity of the feed blends, laboratory measurement precision, wrong data in the formulation tool for ration optimization, actual calcium content of ingredients varies too much around the target.

Investigating the causes related to raw ingredient variability the Pareto diagram highlighted that in the test diet the animal meal and the calcium-carbonate are the main contributors to the product calcium level due to their mineral content and proportion in the recipe. Taking into account that the calcium carbonate is a pure mineral source, less variability is expected.

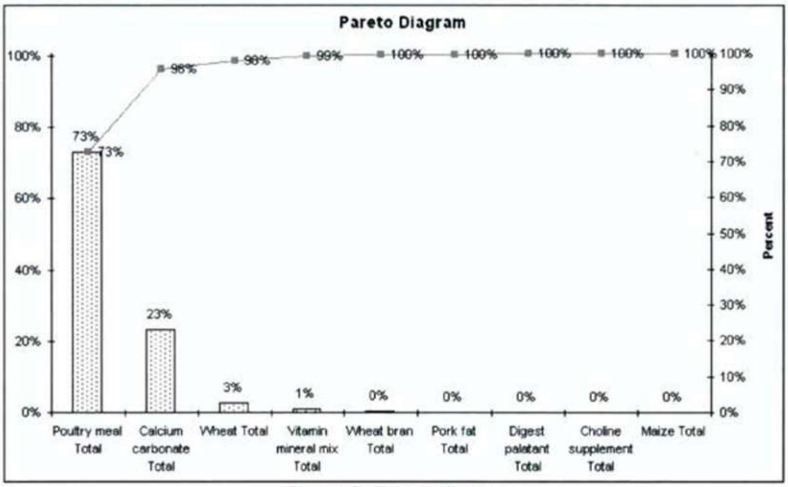

Figure 2: Pareto diagram

Looking at the data available about the calcium content of the animal meal the variability is displayed on a histogram. (Figure 3.) The LSL and USL lines are defining the acceptable, expected range of variation. The statistical analysis compares the actual performance on a parameter in a given time period to the specified limits. The statistical tool also calculates the sigma level of the operation, the average that traditionally would be populated in the linear programming tool for ration formulation, if the similar performance is expected in that period when the product will be produced.

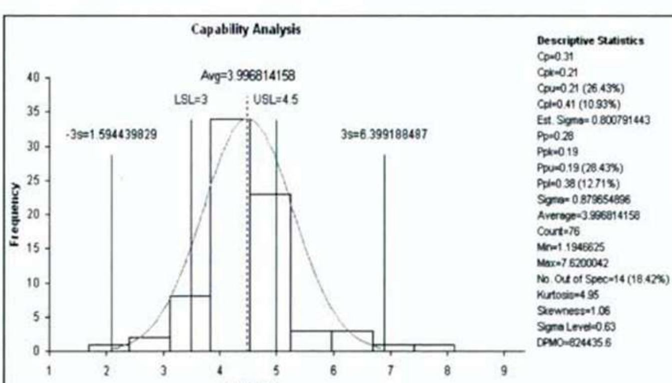

Figure 3. Variability of Calcium content of the animal meal batches

The same dataset (calcium content of every batch) can be graphically displayed and analyzed in time sequence with run charts. Here the additional element in the analysis is the time line, which can flag if any particular movement happens (trend, shift, run) in the characteristic over time. (Figure 4.) The advantage of run sequence plots is that it helps to recognize outliers easily. In this case three data points (three batches: 1.2%, 6.7% and 7.6%) had calcium levels that are considered to be outliers caused by a measurement error or the distribution has a heavy tail.

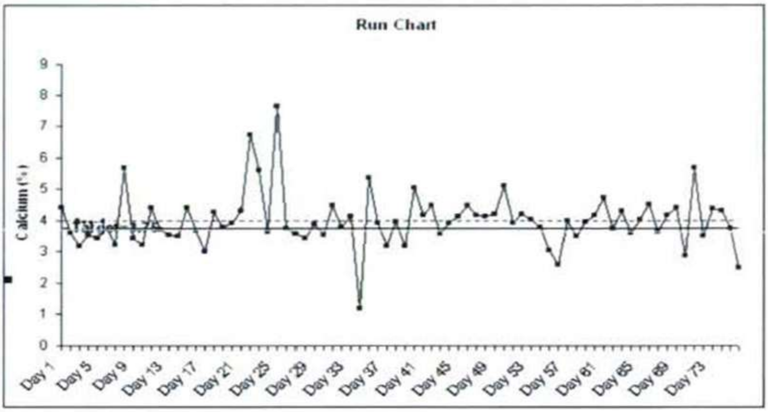

Figure 4: Run chart of calcium content of animal meal batches

Box and Whisker plot (Figure 5.) displays the difference in terms of calcium content of the meals between two suppliers. The plot for the comparison was been made with excluding the outliers. The average calcium level of batches from Supplier B was lower than from Supplier A. The dispersion, spread of the data is more for supplier B than for supplier A. From formulation point of view, if linear programming is used, the average needs to be carefully selected for the software tool, as it impacts the nutritional profile and drives cost of the diet. The other important factor visible in the plot is that the variation of the parameter is different between the two suppliers and this triggers greater variations in end-product calcium around the expected value. If this end-product parameter is a critical-to-customer characteristic, the supplier quality management activities should address this variation.

Figure 5. Box and Whisker plot to compare the data distribution from two suppliers

5. CONCLUSIONS

Component variations drive the variability of end-product characteristics. Six Sigma tools provide logical and reasonable assessment of causes that effect the final product quality. In agri-food operations, where the variability of ingredients are very much dependent on various environmental conditions the good understanding of these variabilities enable the design and manufacturing of products that conform to their specifications and fulfill customer needs. In compound feed production the diets are formulated in specific ranges of characteristics. Linear programming is a deterministic method that considers input data as typical, descriptive figures with ignoring the probability of their occurrence. Therefore when a product expected to contain a nutrient in a certain amount (usually the measured average), in reality, the amounts of this nutrient is going to vary around the average. So, if the linear programming tool finds the optimal diet on the higher edge of the allowed nutrient range, the end product nutrient may be higher than the maximum of the formulation range. This needs to be taken into account when minimum and maximum limits are set for formulation so that the end product will still fulfill customer requirements. Although, tighter ranges in linear programming result in more expensive diets, it may bring quality improvements. The other alternative is using stochastic programming for ration optimizations, where each ingredient has its nutritional profile populated with measured average and the standard deviation.

The commonality of the two formulation methods that both need a sound basis of statistical analysis on input and output data (ingredient variability) to maintain and improve quality. Formulation tools help to quantify the effects of variability and provide powerful solutions on the least cost of the business. Following the principles of Six Sigma and with the help of the Six sigma toolbox, feed or food producers can get into the loop of measuring, analyzing, improving, and controlling factors that influence quality improvements, even though achieving Six Sigma performance may not be realistic for some of the processes in the industry.

Customer orientation can be realized along the supply chain if the supplier performance is measured against delivering components according to specifications and these components can be effectively and safely used in end products. Dealing with primer agricultural products, the compound feeds may have tighter specified ranges than what the ingredients would fit into. This case the variability needs to be managed and set aside by proper differentiation of quality sub-groups either by the suppliers or the producer. Supplier chain quality management can help to tackle these problems, with the condition of having adequate data to do the analysis with Six Sigma tools. To assess and improve quality of supplier processes Six Sigma tools can be used as well, either by the vendor, or with the facilitation of the buyer firm. This second case could promote and enhance customer-orientation in the supply chain.

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